IEP PROPOSAL for 2004

Program Element Title: Evaluation of readily available satellite imagery data for the remote sensing of water quality constituents in the San Pablo Bay and the Sacramento-San Joaquin Delta

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I. Program Element Management

A. Program Element Description/ Problem Definition

1. History or Background - Briefly describe the situation leading to the program element.

Estuaries are dynamic systems undergoing seasonal variations driven by the climate and daily changes caused by tidal movements. They also typically feature branching and meandering, variable bathymetry and complex hydrodynamics. As a result, they are characterized by high spatial and temporal variability. Because of technical and financial constraints however, environmental monitoring programs must balance density of coverage in time and space with the number of variables monitored and the precision of measurements. Consequently, our understanding of spatial and temporal heterogeneity in estuaries such as the San Francisco Bay and Sacramento-San Joaquin Delta is based on generalizations from measurements made at a limited number of sampling stations. The techniques presently used by the IEP Environmental Monitoring Program (EMP) for water quality monitoring involve continuous *in situ* measurements and the monthly collection of discrete water samples for laboratory analyses. Discrete water quality sampling provides the most comprehensive and accurate measurements for single points in time and space. Laboratory analyses of 11 variables (nutrients, solids) from 11 stations, and chlorophyll *a* and pheophytin *a* from 22 stations are performed each month. Field measurements (dissolved oxygen, turbidity, specific conductance, temperature, secchi depth and chlorophyll fluorescence) are taken monthly at 22 stations. The EMP also operates seven year-round and two seasonal automated monitoring stations which provide continuous time-series for particular points in space. Hourly recorded variables include specific conductance, dissolved oxygen, pH, temperature and chlorophyll fluorescence. Continuously recording data loggers on the RV San Carlos allow for constituent transects in space and time (dissolved oxygen, temperature, specific conductivity, turbidity and chlorophyll fluorescence). However, none of theses techniques provide a truly system wide (or synoptic) view of Bay-Delta water quality. Consequently, many uncertainties remain concerning the spatial variability of monitored variables in this system.

The strength of remote sensing techniques lies in their ability to obtain measurements simultaneously over a wide area in order to provide a comprehensive view of their variation in space. Combined with data obtained through our current monitoring techniques, remote sensing is potentially useful to 1) reveal system wide spatial patterns of water quality constituents; 2) relate those patterns to geomorphology, hydrology, land-use and land-cover; 3) provide spatial context to our point and transect samples; 4) help us re-assess the optimal location of our point and transect sampling; and 5) develop and test interpolation techniques to generalize data obtained along transects and at discrete locations. Potential future applications of interest to IEP include mapping the extent of algal blooms; studying the patterns of temperature in relation with fish reproduction; relating sediment and chlorophyll *a* patterns to X2, water year hydrologic conditions, flooding of Delta islands, etc.

In their recent review of the Environmental Monitoring Program, the IEP Science Advisory Group (IEP SAG, 2002) has demonstrated interest in the potential of remote sensing to the EMP. For instance, members of the SAG recommend that the IEP should examine the value of new integrative tools, such as remote sensing, for future EMP monitoring. "Both satellite and airborne platform sensors offer comprehensive sampling of a variety of parameters important to, and measured by, the EMP at a variety of resolutions (29-m to sub-meter, depending upon sensor and platform), e.g., chlorophyll/fluorescence, turbidity/suspended sediment, DOC. Although such remote sensing is often limited by the same "snapshot" biases as much of the EMP sampling design, it does provide the power of broad spatial coverage that could be calibrated by strategic in situ EMP ("groundtruthing") sampling over the Bay-Delta." (IEP SAG, 2002, p10). Jonathan Sharp (re. phytoplankton monitoring) wrote: "Even larger areal coverage could be made by remote sensing. Satellite imagery is available on a daily basis through the SeaWifs program of NASA and NOAA. Currently this imagery is considered very accurate for chlorophyll determination in clear oceanic waters but quantitatively less accurate in nearshore waters. There are efforts to make nearshore imagery more accurate by accommodating for suspended sediments, bottom reflection, and colored dissolved organic matter. Recent efforts by NOAA and NASA with airplane overflights using laser fluorometry appear to be very accurate for east coast nearshore waters. It is probable that similar overflights could be made routinely over the Delta and San Francisco Bay waters to coincide with boat sampling for ground truth and this should be explored. These remote sensing techniques allow the highest density synoptic picture of the phytoplankton distribution in the waters of interest and when done in conjunction with the continuous and discrete sampling allow very powerful field information." (IEP SAG, 2002, p19). Alan Jassby (re. phytoplankton and suspended particulate matter (SPM) monitoring) noted: "I believe that remote sensing deserves real attention here. For much of the Delta much of the time, phytoplankton are simply too small a fraction of SPM to be detectable remotely. But blooms should be evident and, as the Delta continues to clear, the sensitivity will improve. Irrespective of the current situation with phytoplankton, remote sensing will give a better assessment of Delta-wide SPM concentrations and of its spatial and temporal variability. This will help define the trend in SPM more accurately as well as resolve outstanding issues over the origin of this trend. Given the controlling influence of SPM on primary production directly through effects on k_d and indirectly through effects on primary consumers, this should be a higher priority item." (IEP SAG, 2002, p28). Alan Jassby (again, re. water quality monitoring), concluded: "A much bigger emphasis on remote sensing may be the next most important move of this revision." (IEP SAG, 2002, p31). Evaluating remote sensing techniques has also been identified as an important special study in the comprehensive 2001-2002 EMP Review (EMP Review and Recommendations, Draft III, Oct. 2002).

Satellite imagery is used routinely to monitor the water of oceans. Closer to our purpose, Landsat imagery has been used to map water quality constituents such as suspended sediments, chlorophyll, and temperature in lakes (Ritchie et al. 1990, Ritchie et al. 1994, Yacobi et al. 1995; Kloiber et al. 2002a and 2002b). It has also been used for coastal waters (Curran and Novo, 1988), coastal lagoons (Dewidar and Kehdr, 2001) and estuaries (Baban, 1997). We have not been able to locate published examples of such work in the San Francisco Bay or the San Joaquin – Sacramento Delta, with the notable exception of the recent work by Ruhl et al. (2001). We have however been made aware of two previous attempts, the results of which were never published for undocumented reasons.

2. Purpose of program element in explicit terms

a) Questions to be answered. If at all possible, phrase as a testable hypothesis.

The main question we will address is: can satellite imagery be used to improve system-wide assessment of important water quality variables in the Upper San Francisco estuary?

Associated questions are:

1) Which water quality constituents can we map using readily available satellite data?
2) What precision and accuracy can we achieve in the measurement of theses constituents?
3) What are the constraints in terms of available instrumentation, periodicity of data acquisition, climatic conditions, ancillary data gathering, etc?
4) What extent of mapping is achievable for each event given the available resolution of the remotely sensed data, the acquisition of ground reference data and the variability of Bay-Delta waters?
5) What are the limitations of remote sensing methods in the Upper San Francisco Estuary? Which ones can be used for future studies by IEP? Which methods did not work and why? What potential improvements to the methods should we consider?
6) What are the implications for EMP water quality monitoring? Can we use the new insights into spatial variability for optimizing the location and operation of the discrete sampling and continuous monitoring stations?

b) Objectives of the program element.

We emphasize that the objective of this project is not to develop new and expensive remote sensing techniques but to evaluate the feasibility and usefulness of applying established techniques in the Bay-Delta environment using inexpensive and readily available remotely sensed data.

c) How will success be determined?

Success will be determined by the publication and dissemination of the answers to the questions listed in item 2 a) above. Given the scarcity of published information concerning the application of established remote sensing techniques for monitoring water quality in the San Francisco Bay and the complete lack of information regarding such applications in the Sacramento-San Joaquin Delta, providing such information to IEP and the larger estuary research community would be a valuable achievement.

3.How will data and information from program element be used?

The primary goal of this project is to acquire and disseminate information about the feasibility and usefulness of using remote sensing techniques in the Bay-Delta environment for IEP ongoing monitoring or special studies.

Subsequent studies may then use the information produced by this project, pursuing two goals:

1) to exploit the observed strengths of the methodology to answer more specific questions of interest to IEP such as: mapping the extent of algal blooms; studying the patterns of temperature in relation with fish reproduction or migrations; relating sediment and chlorophyll *a* patterns with X2, water year hydrologic conditions, the flooding and/or restoration of Delta islands.
2) to attempt to correct weaknesses identified by this evaluation. At this later stage only, tools such as airborne laser fluorometry, mentioned by IEP SAG members, may come into play.

4.What are the biological implications of the program element?

The distribution and growth of aquatic organisms within estuary habitats varies with salinity, suspended solids, turbidity, temperature and nutrient concentrations. Suspended sediments, chlorophyll *a*, colored dissolved organic matter, oil and temperature are the water quality constituents most readily measured by remote sensing techniques. Suspended sediments are important because they contribute to turbidity and thus condition the amount of sunlight that penetrates the water and is available for primary production. Suspended sediments are also important as a substrate for microbial organisms and because they are closely correlated with the concentration and transport of some toxics. Mapping suspended sediment concentrations may provide valuable information to better understand sediment transport throughout the Bay-Delta system. The rates of most chemical and biological reactions increase with temperature. Primary production is correlated with temperature and many aquatic organisms and fish species use water temperature as a cue for reproductive timing and migration. Chlorophyll *a* and other pigments are measures of phytoplankton biomass at the bottom of the food web. The spatial variation in the concentration of these pigments may also help in understanding algal blooms that are detrimental to water quality for human consumption. Concentration of dissolved organic matter is associated with organic carbon sources and fluxes in the estuary. Mapping of these fluxes is important to understand the contributions of tidal marsh, flood plain, agricultural and urban waste, and the export through the water projects; to identify areas vulnerable to increased disinfection byproduct production; and to plan and monitor ecological restoration.

B. Project Resource Needs

1.Budget

a) Personnel (includes overhead)	10% time of a Staff Environmental Scientist (Anke Mueller-Solger) for planning, water sampling, discussion and reporting of the results.	($18,720) *
	50% time of a Staff Environmental Scientist (Marc Vayssières) for planning, water sampling, data analysis and reporting of the results.	($93,600) *
b) Operation costs	Research Vessel San Carlos (or USBR RV) and crew time to acquire optical water properties measurements and water samples and profiles on 6 day cruises to coincide with satellite passage.	$12,000
Data costs	Purchase of 12 Landsat7 TM scenes from USGS EROS Data Center	$7,200
Equipment costs	No equipment will be purchased specially for this project.	
Collaborators costs	Calibration and operation of instruments to measure water optical properties (Shelly Benoit). Help with algorithm development and data analysis by Professor Kudela of the University of California at Santa Cruz.	$10,000
Total budget		$29,200

* Note Anke Mueller-Solger's time will be covered by the IEP EMP Program, Marc Vayssières' time will be covered by DWR CalFed Science Program.

2.Personnel needs

The project will be conducted in collaboration and consultation with Prof. Raphael Kudela of the Biological and Satellite Oceanography Laboratory at UCSC and one of his PhD students, Shelly Benoit.

a) Field activities (number of people per class or category, i.e. biologist, boat operator, scientific aide, etc.)

A boat operator will be needed for 6 special day cruises to coincide with satellite overflight (included in operation costs).

b) Laboratory and office activities (number of people per class or category, i.e. biologist, senior laboratory assistant, scientific aide, etc.)

Laboratory analyses will be performed by DWR's Bryte laboratory, as part of DWR overhead.

3. Equipment needs

a) Boats - which type and size of boats will be needed and when

The DWR Research Vessel San Carlos, or a USBR RV, will be needed for 6 special day cruises to coincide with satellite overflights (see probable Landsat7 schedule for 2004 in Appendices). Additional work will take advantage of EMP routine monitoring cruises.

C. ESA Considerations

1. Will project result in the "take" or have the probability "taking" any state or federally listed threatened or endangered species?

No take will result from this project.

2. If so, please estimate the number per species/race.

Not applicable.

3. If the program element will result in the "take" or capture of any state or federally listed species, will this "take" be covered by IEP Biological Opinions or some other Biological Opinion?

Not Applicable.

D. Due Dates and Products

1. What is the program element timeline and what is the completion date?

One year and a half (Jan.2004-June 2005) for data acquisition, analysis and publication of results.

2. What products or deliverables will the program element produce and what are the due dates for them? Include both dates for drafts and final products.

PRODUCT	*Due Date*
Review of published and (if documents can be identified and obtained by us) unpublished previous relevant work in the Delta	June 2004
Data acquisition, analysis and storage in EMP databases.	Dec. 2004
Presentation at the IEP conference	Feb. 2005
IEP newsletter article	Winter 2004

IEP technical report with recommendations for EMP monitoring design	June 2005
A contribution to the IEP web site including a summary of the study and all the resulting maps of the Bay-Delta	March 2005
A peer reviewed paper describing our methodology and our results	Submitted March 2005

3. Will any databases be created for or added to for this program element?

Water sampling, optical properties measurements and water quality profiles data will be added to existing EMP databases. Satellite imagery data and band ratio grids will be stored in GIS raster format.

4. Will the data be uploaded to the IEP server and if so, when?

Data will be uploaded if the IEP management team requests it. Satellite imagery will be shared with interested parties. Project specific data will be provided to others on request once the results of this project have been published.

II. Program Element Measurement and Data Acquisition

A. Choice of satellite imagery

Remote sensing monitoring of water quality is limited to measuring those substances or conditions that influence the optical or thermal characteristics of surface water. Suspended sediments, pigments such as chlorophyll *a*, colored dissolved organic matter, oil and temperature are the water quality constituents most readily measured by remote sensing techniques. Remote sensing instruments vary in terms of ground resolution, number and position of spectral bands, periodicity of acquisition, availability and price.

Some satellite have carried instruments acquiring multispectral data for many years. For example, the Advanced Very High Resolution Radiometers (AVHRR) have been mounted on NOAA satellites since 1979. The current NOAA satellites with AVHRR, NOAA-12 and NOAA14 overpass the San Francisco bay daily and collect data in five broad bands of the electromagnetic spectrum (2 in the visible and near infra red, and 3 in the thermal infra red). AVHRR maximum resolution is 1100 m pixels on the surface of the Earth. Multispectral images of the earth are also available from Landsat satellites. Launched in 1999, Landsat 7 is the latest in a series of satellites that have been providing multispectral images continuously since 1972. Landsat7 overpasses the San Francisco Bay and Delta every 16 days. The instrument on board Landsat 7 is the Enhanced Thematic Mapper Plus (ETM+). It has eight bands sensitive to different wavelengths of visible, infrared, and thermal radiation with a high ground resolution of 15-30 m pixels (see table).

Table 1. LANDSAT 7 ETM+ Spectral and Spatial Resolution.

Band Number	Spectral Range (microns)	Ground Resolution (m)
1	.45 to .52	30
2	.53 to .61	30
3	.63 to .69	30
4	.78 to .90	30
5	1.55 to 1.75	30
6(L/H)	10.4 to 12.5	60
7	2.09 to 2.35	30
Pan	.52 to .90	15

During the past few years, space born instrumentation optimized for water quality monitoring has become operational. The Sea-viewing Wide Field-of-view Sensor (SeaWiFS) was launched August 1, 1997. SeaWiFS scans 90% of the ocean surface every two days. SeaWiFS acquires data within 8 bands of the spectrum specially chosen to detect chlorophyll and dissolved organic matter, and to correct for light scattering in the atmosphere. SeaWiFS was designed to monitor oceans where light absorption is primarily due to the photosynthetic pigments (chlorophyll) present in phytoplankton. SeaWiFS data is obtained at 4 km pixel resolution over most of the world's oceans and 1 km resolution is available for specific regions. Another sensor used for ocean monitoring, The Moderate-resolution Imaging Spectroradiometer (MODIS) was launched on the Terra satellite and has provided data since 2000. It passes every point on the globe every 1-2 days and acquires data within 36 discrete spectral bands. MODIS greatly improves upon the heritage of the NOAA Advanced Very High Resolution Radiometer (AVHRR). MODIS maximum resolution for the wavelengths used in water quality monitoring is 500 m pixels.

Ruhl et al. (2001) have used AVHRR to analyze the variability of suspended sediments in San Francisco Bay and concluded that using higher resolution images, such as Landsat TM images, would be a great improvement. Kudela (personal communication) has used SeaWiFS in the San Francisco Bay and concurs that a 1km pixel resolution is marginally useful in the Bay and much too coarse for the Delta. Although other researchers have used Landsat TM to map water quality constituents in lakes, lagoons and estuaries, we have not found any such use published for the Sacramento San Joaquin Delta.

We propose to use Landsat TM data because it has been used for water quality work in other environments, it has sufficient resolution (30 m pixels) for the bays and main channels, passes over the Delta every 16 days, and is inexpensive. Another advantage is that Landsat has made consistent measurements for the past 20 years. The historical Landsat data could thus be related to some of our historic water quality data in future study, provided that sufficiently accurate empirical models relating water quality data and Landsat data can be developed in the project proposed here.

B. Sample Site Selection

1.Brief description of study area and list of sample sites

The study area will be bounded by the intersection of the extent of the EMP water quality sampling program and that of the Landsat7 scene referenced as path 044/ Row034 (see figure 1 & 2 in appendices).

C. Sampling Procedures, sample processing and analysis

We intend to acquire future Landsat7 TM+ scenes and gather concurrent ground reference data in order to first establish and then assess numerical relationships between remotely sensed reflectance values, *in situ* optical water properties, and *in situ* or lab measurements of water quality constituents.

1. What parameters will be measured? When?

We will concentrate on the water quality constituents most likely to be mapped using Landsat7: water temperature, suspended sediments, chlorophyll a and colored dissolved organic matter (CDOM). Ruhl et al. (2001) concluded that using *in situ* sensors in open water areas rather than on the shoreline would be preferable. The EMP currently has the capability to record continuous horizontal transects of turbidity, chlorophyll fluorescence and water temperature using flowthrough instrumentation on board the RV San Carlos (or USBR RV). We intend to add the capability to record CDOM profiles by the time this study will begin. We propose to record these variables during cruises along three transects to coincide with satellite overpasses. These three transects will have been chosen to be representative of the variations in salinity, hydrology and geomorphology present in the Delta and San Pablo Bay (see figure 2). We will also collect a series of discrete water samples for analysis of suspended solids, chlorophyll, phytoplankton composition, and dissolved organic matter along these transects. Professor Kudela will provide instrumentation and expertise for *in situ* measurement of optical properties of the water, and his PhD student, Shelly Benoit, will be present on the cruises to operate the equipment. She will also accompany us on some of EMP's regularly scheduled water quality cruises to acquire additional optical properties data for other parts of the Delta.

We intend to revisit each of the three transects once during subsequent passages of the satellite to validate the relationships (between ground and remotely sensed data) derived from the first set of cruises.

2. Methodology (list what gear or equipment will be used)

Water quality samples will be processed by DWR's Bryte laboratory following EPA approved protocols.

Water quality profiles will be acquired with existing equipment used for EMP water quality cruises (namely Turner 10-AU fluorometers equipped with appropriate optical kits and a temperature probe).

Water optical properties will be measured with the following instruments provided by Prof. Kudela:

1) A Biospherical Instrument PRR-600/PRR-610 package. This package provides measurements of Photosynthetic Available Radiation (PAR), reference irradiance, downwelling irradiance and upwelling radiance at 7 channels matching those of the satellite sensors. These data will be processed to extrapolated values of downwelling irradiance and upwelling radiance just beneath the surface [$E_d(0^-\lambda)$ and $L_u(0^-\lambda)$], and calculated values for the spectral diffuse attenuation coefficients [$K_d(\lambda)$] will be determined. Processing will be carried out using the routines described in Siegel et al.(1995).
2) A HOBILabs HydroScat-6, which is an instrument capable of measuring backscatter (b_b) at six wavelengths as a function of depth. This instrument is critical to the development of better semi-analytical estimates of chlorophyll, since the spectral backscatter parameter is likely to vary widely in the Bay and Delta.

Satellite imagery data will be processed partly using the IDL programming language in Prof. Kudela's lab at UCSC and the GIS software Arc/Info available on EMP's Computers at DWR. Statistical analyses will be performed using the S+ Software and other relevant software packages.

D. Data Reduction, Analysis and Reporting

1.What procedures for calculations and statistics will be used?

Two types of approaches are used to relate water color (i.e. spectral reflectance) data acquired by satellite to actual constituent concentrations measured *in situ*: empirical and semi-analytical models.

Empirical models use regression techniques to relate pixel values in one or a combination of spectral bands in the satellite image to actual constituent concentrations measured in the water. Many such models have been documented in the literature. For instance, Curran and Novo (1988) review empirical models and references for relationships between suspended sediments and reflectance for coastal waters. Ritchie et al. (1990) used empirical models to relate Landsat TM data to suspended sediments, chlorophyll and temperature in a lake in Mississippi. Tassan (1998) present a procedure for the determination of chlorophyll and suspended sediments concentrations in shallow water from Landsat TM data. Baban (1997) used empirical models for monitoring suspended solids, turbidity, temperature, chlorophyll in Breydon Water Estuary. This type of model was also used by Ruhl et al. (2001) to map suspended sediment concentrations in the San Francisco Bay. However, previous work has also shown that using data from broad band spectral sensors, such as Landsat TM, in empirical model may not provide satisfactory relationships for chlorophyll measurements in waters whose reflectance is dominated by suspended sediments (Ritchie et al.1994).

Semi-analytical models are both more ambitious and more difficult in that they are using data relationships to estimate some of the parameters of physical equations of the optical properties of the water column. In a nutshell, spectral reflectance can be used to characterize the optical properties of a water column integrated over one optical depth, because it can be demonstrated that the water color, measured by a satellite as remote sensing reflectance (R_{rs}), is a function of the inherent optical properties (IOPs) of the absorption coefficient, a(λ), and the backscattering coefficient, b(λ). To first order, a(λ) and b(λ) are made up of the sum of their components, including water, phytoplankton, sediments, detritus, etc. This relationship can be described as follows (from Lee et al., 1994):

$$R_{rs}(l) = \frac{ft^2}{Q(l)n^2}\frac{b_b(l)}{\left[a(l)+b_b(l)\right]} \cong \frac{L_u(l)}{E_d(l)}$$

where f is an empirical factor (Gordon et al., 1975; Morel and Prieur, 1977; Kirk, 1991; Morel and Gentili, 1996), t is transmittance of the air-water interface, Q(λ) is the upwelling irradiance to radiance ratio, and n is the real part of the index of refraction. In general, the first part of the equation, f/Q and t^2/n^2, can be treated as constants, if we make the assumption that they don't vary strongly with wavelength and that the satellite sensor maintains a known viewing angle (Gordon et al., 1988; Morel and Gentili, 1993). This leaves a simplified equation of the form:

$$R_{rs}(l) = \sum_{i=1}^{2} \mathrm{l_i}\left[\frac{b_b(l)}{\left[a(l)+b_b(l)\right]}\right]^i$$

where $\mathrm{l_i}$ represents the constant terms from the first equation. Often this is further simplified by considering only the linear form of the equation:

$$R_{rs}(l) = \text{constant}\,\frac{b_b(l)}{\left[a(l)+b_b(l)\right]}$$

If we then expand the absorption and scattering components into their in-water constituents, and substitute them into this equation, we end up with the following:

$$R_{rs}(l) = \text{constant}\,\frac{b_{bw}(l)+b_{bp}(l)}{\left[a_w(l)+a_{ph}(l)+a_{dm}(l)+b_{bw}(l)+b_{bp}(l)\right]}$$

Where b_{bw} and a_w refer to the scattering absorption by pure water (assumed to be known), b_{bp} refers to particle scattering, a_{ph} is absorption due to phytoplankton, and a_{dm} is absorption to colored dissolved and particulate matter (following the notation of Garver and Siegel, 1997).

Several forms of further simplifications of these equations can be used depending on which constituent or combination of constituents (i.e. phytoplankton, sediments or organic matter) dominate absorption and scattering in the water column.

We propose to develop traditional empirical models for temperature, suspended sediments, chlorophyll and dissolved organic matter using the three regional cruises described above. Additional water quality data from continuously monitoring stations will be used to extend the models to the rest of the Delta. Additional water optical properties acquired on regular cruises will also be used to extend the regional empirical models to the rest of the delta by providing a link between what is seen by the satellite and *in situ* water quality measurements. For examples of how *in situ* water optical properties measurements can be used in combination with Landsat TM see Harma et al. (2001) and Yacobi et al. (1995). The three sets of regionally derived models will be validated with data acquired during the three corresponding subsequent cruises.

We also propose to develop semi-analytical models to attempt to resolve some of the expected limitations of the empirical models. However, such models must be considered as experimental and we do not expect them to be of practical use for water quality monitoring within the span of this project.

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IV.Appendices

Landsat7: Expected return dates over S.F. Bay-Delta

(all times circa 10:30 PST)

10-Jan-04
26-Jan-04
11-Feb-04
27-Feb-04
14-Mar-04
30-Mar-04
15-Apr-04
01-May-04
17-May-04
02-Jun-04
18-Jun-04
04-Jul-04
20-Jul-04
05-Aug-04
21-Aug-04
06-Sep-04
22-Sep-04
08-Oct-04
24-Oct-04
09-Nov-04
25-Nov-04
11-Dec-04
27-Dec-04

Figure 1: Landsat7 scene path044/row034 acquired on 09/30/2001

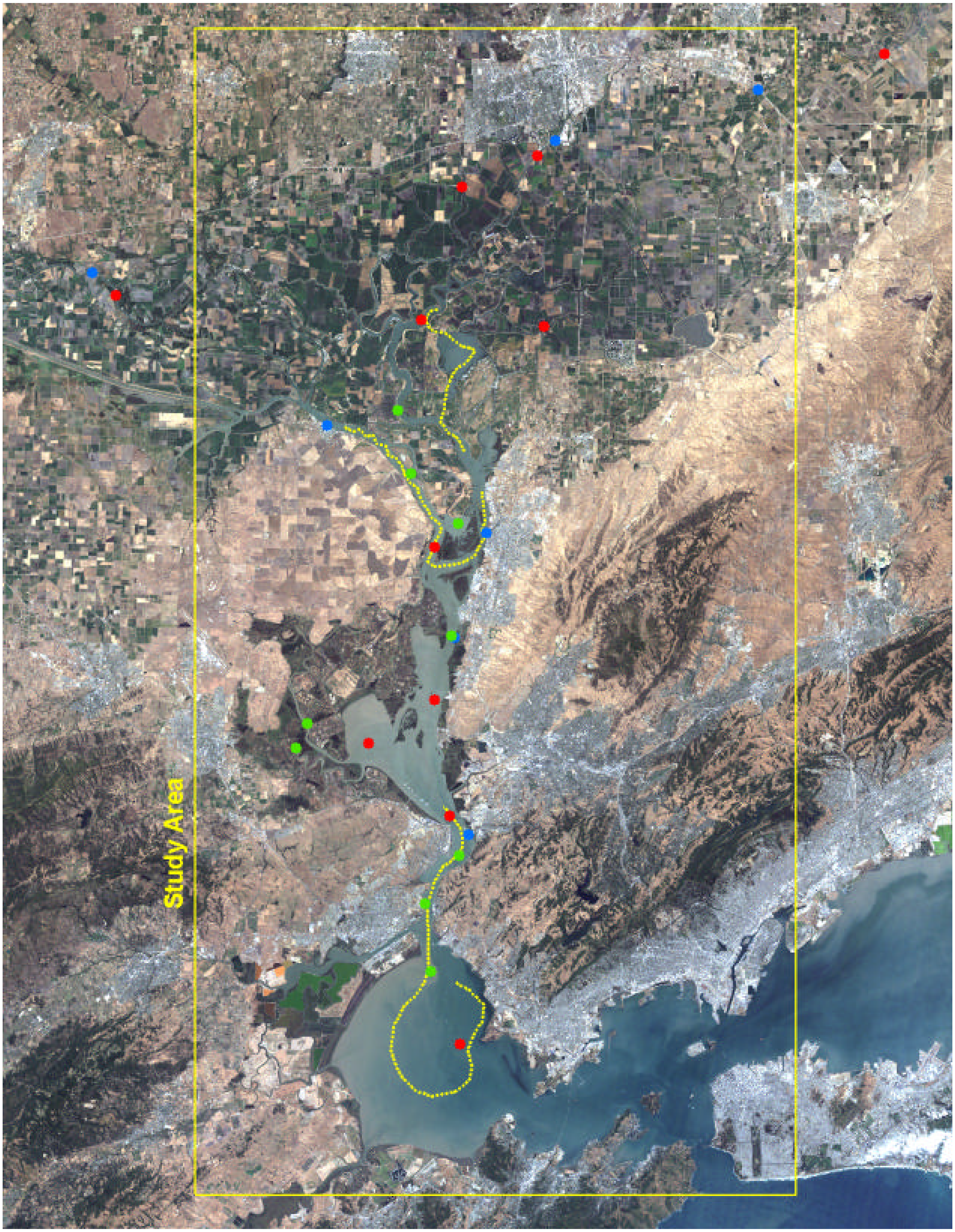

Figure 2: Study area featuring: 1) Three ground reference transects (yellow dotted lines); 2) EMP regular water quality stations, ie. a) red dots: stations with monthly lab analyses, field measurements and chlorophyll extractions; b) green dots: stations with monthly field

measurements and chlorophyll extractions; and c) blue dots: automated continuously monitoring stations.